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DIAGNOSTIC OF PMS NATURE IN HERBIG
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**Final Report
IUE Observing Program
Research Grant # 5798**

14th Episode

"The Mg II Lines as Diagnostic of PMS Nature in Herbig Ae/Be Stars"

Goals. The main objective of this program was to observe some newly discovered and previously unobserved Herbig Ae/Be (HAeBe) stars with IUE. A previous archival study suggested that there was a full range of profiles in the Mg II lines for these objects; ranging from the double peak emission to the narrow absorption lines. We have found by studying the IUE data of main sequence B and classical Be stars that the P Cygni profiles in the Mg II lines in HAeBe stars are truly unique and are the signature of accelerating winds in their extended circumstellar material. We argue, for the purposes of this proposal, that the structure of the Mg II lines was a superior diagnostic of the dynamical activity and ultimately of the PMS nature of these objects. This program was a follow up study of several interesting intermediate-mass stars with the goal of classifying these objects based on the shape of their Mg II lines.

Observations. This IUE observing proposal was awarded 2 US1 and 2 US2 shifts. These shifts were used to observe the following targets with the LWP camera mostly in the high-dispersion mode through the large aperture. Four of these images were taken in low-dispersion in order to assess the overall spectral energy distribution at that photometric state. A total of 16 images were acquired during the 4 shifts assigned to this program. Additional data taken under previous related programs were retrieved from the IUE archives and used in the overall analysis. Most of the new targets observed in this program were obtained from previous searches of young objects conducted by team members (University of Amsterdam collaborators), based on optical photometry, spectroscopy, narrow filter imaging and near-IR photometry.

Mg II emission line profiles among the HAeBe stars have been detected. The new data obtained through this program help us to detect Mg II variability in several stars, especially HR 5999 (see paper on this star listed under publications). Moreover, the interpretation of this variability was in term of episodic mass infall onto the central source. The overall shape of the Mg II lines allow us to classify the observed sample (archive and new data) into four major groups:

1. Very pronounced P Cygni line profiles typical of accelerating winds in a non-spherical shell are seen for the earlier stars with strong IR excesses. The prototype of this class of objects is AB Aur.
2. Doubled-peaked emission is seen in the later type stars with strong IR excesses. The Mg II lines of star HR 5999 of spectral type A5-7 III is representative of this class.
3. Weak stellar emissions of Mg II superimposed in their deep IS absorptions. For some of these stars the underlying emissions appear to be blue- or red-shifted with respect to the IS absorption. A typical case for this class is star HD 179218.
4. Sharp absorption resembling an interstellar line is seen in hot stars with weaker IR excesses. The weak emission line star HD 53367 is an example of this class. This group also include stars with probably stellar contributions to the IS absorptions such is probably the case of HD 141569 and HD 97048.

The lower mass PMS objects, namely T Tauri stars, also present P Cygni profiles or double/single peaked Mg II lines in emission. Unfortunately, only a handful of T Tauri stars have been observed in high-dispersion with IUE, however, all of them show these P Cygni profiles, such as SU Aur, T Tau, RW Aur, etc. These emissions are interpreted as the signature of outflows necessary for the transport and subsequent loss of angular momentum of the central source.

Conference Trips. Funding provided through this observing program allowed me to attend three international scientific meetings.

1. The 27th ESLAB Symposium "Frontiers of Space and Ground-based Astronomy/ The Astrophysics of the 21st Century". May 10-14, 1993, ESTEC Noordwijk, The Netherlands.

In this I presented several papers related to my IUE on-going research, including the work related to this observing program.

2. *"Stars, Gas and Dust in the Galaxy", scientific meeting honoring Dr. Eugenio Mendoza. August 25-27, 1993, Mexico City.*

I was invited to present a review paper (listed as number 7 in publication list) on the nature of the accretion phenomena in intermediate-mass PMS stars.

3. *First International Meeting on "The Nature and Evolutionary Status of the Herbig Ae/Be Stars", October 26-29, 1993, Amsterdam, The Netherlands.*

I was one of the main organizer of this meeting and the chief editor of the conference proceedings, which are published in the Conference Series of the Astronomical Society of the Pacific as Volume 62, "The Nature and Evolutionary Status of the Herbig Ae/be Stars", editors: P.S. The, M.R. Perez, E.P.J. van den Heuvel.

Publications. Most the work accomplished in this program has been presented in conference papers and/or refereed papers. These papers are an integral part of this final report. In the following list, I present the titles of the refereed papers, complete references and a brief outline of the content and their relation to the main goals of this program.

1. *"The new Be-type star HD 147196 in the Rho Oph dark cloud region", 1993, A&A, 269, 181, P.S. The, M.R. Perez, M. van den Ancker, D. de Winter.*

The IUE data of this star were analyzed and interpreted as part of the Mg II research project HAeBe stars and it was found that this object was indeed a classical Be star surrounded by very young objects in the Oph dark cloud.

2. *"UV spectral variability in the Herbig Ae star HR 5999: XI. The accretion interpretation", 1993, A&A, 274, 381, M.R. Perez, C.A. Grady, P.S. The.*

This is the most important paper dealing with a new interpretation of the variability of several iron-peak lines such as Mg II, in this star. Several of the observations reported here were obtained through this observing program.

3. *"Radio Continuum Observations of the Herbig Ae Stars HD 163296 and HR 5999", 1993, AJ, 106, 2000, D.A. Brown, M.R. Perez, F. Yusef-Zadeh.*

The new VLA data obtained for these stars were combined with new IUE data obtained almost contemporaneously to the radio observations. The main result here is the detection of radio continuum at 3.6 and 20 cm in HD 163296, which had never been detected before, whereas, no signal was detected at the position of HR 5999.

Star	Number of Images	LWP Image Numbers
HD 37411	1	21654
HD 50138	2	21653, 22631
HD 76534	1	20660
HD 85567	1	20659
HD 87643	1	20595
HD 94509	1	20596
HD 98922	2	20655, 22611
HD 100546	1	20656
HD 101412	1	20657
HD 141569	1	20658
HD 144668/HR 5999	4	21267, 21268 22612, 22632

The most impressive result was the detection of well-developed P Cygni profiles in the Mg II lines in the star HD 98922. This star was suspected to be a classical young star, however, this was the most important confirmation of its nature.

Interpretation. For the intermediate pre-main sequence (PMS) stars no particular test has been found to discriminate between the main sequence and PMS objects. Among cool stars, the depletion of lithium is relatively reliable age indicator and has proved to be very useful in distinguishing between T Tauri stars and more evolved objects. Consequently, the HAeBe class seems to be contaminated with other emission-line objects, such as proto-planetary nebulae, classical Ae and Be stars, evolved stars, etc.

Recent developments in the study of HAeBe objects seem to favor the scenario of accretion as the mechanism to explain many observational features in some of these objects. In this scenario the Mg II lines appear to be the signature of accretion winds arising at high latitudes from the disk. Theoretical models predict the existence of a smooth range of P Cygni profiles and single peaked emission for several lines detected in the ultraviolet as a function of the geometrical alignment of the disks. Outflows and their associated mass loss, as detected by the ultraviolet emission lines, are predicted by the theory of accretion around compact object. Without exception, all the *bona fide* HAeBe stars present P Cygni profiles in their Mg II line profiles. This was further verified through the additional data obtained in this observing program. Furthermore, gradual differences in the

4. *"A new catalogue of members and candidate members of the Herbig Ae/Be (HAeBe) stellar group"*, 1994, A&A, 104, 315, P.S. The, D. de Winter, M.R. Perez.

This paper was the result of several years of on-going work searching for new HAeBe stars. The introductory text for this paper and the selection criteria for the stars included were strongly influenced by the results of our Mg II project for these objects. This catalogue contains 287 young objects (a previous catalogue included only 57 stars).

5. *"The evidence of clumpy accretion in the Herbig Ae star HR 5999"*, 1994, Ap&SS, 212, 115, M.R. Perez, C.A. Grady, P.S. The.

This was a more detailed study of the evolutionary status of HR 5999 based on many indicators, such as the Mg II lines, H and Lyman alpha emissions, IR excess, luminosities, etc. Several signatures of accretion were found especially in the UV lines, such as the redshifted absorption component extending to several hundred km/s.

6. *"Detection of accreting circumstellar gas around weak emission-line Herbig Ae/Be stars"*, 1994, Ap&SS, 212, 107, C.A. Grady, M.R. Perez, P.S. The.

This paper advances a very provocative idea based mostly on IUE data. Objects with no emission lines visible in their spectra could indeed be very young and support substantial amount of gas accretion from their surroundings. This paper further discussed the case of HD 176386, which does not present P Cygni profile in the Mg II lines.

7. *"The Clumpy Accretion in Herbig Ae/Be Stars"*, 1994, M.R. Perez, P.S. The, Rev. Mex. A&A, 29, 54.

This review includes all the optical, radio, IR and UV signatures that are indicative of clumpy accretion in HAeBe stars. The evidence seems to indicate rather convincingly that various amount of accretion are detected in the line-of-sight toward these objects. The Mg II study is an integral part of the discussion and arguments in this paper.